The purpose of the Rational Fire Modeling/Analysis is to determine the required capacity of the Rotunda smoke exhaust system. The purpose of a smoke exhaust system is to protect the means of egress in the event of a fire. If there is a fire in the Rotunda, the smoke exhaust system will maintain the ceiling smoke level above the top floor level so that building occupants can exit from the top floor balcony.

The Rational Fire Modeling/Analysis uses computer simulation to model a fire using the actual building combustible load, volume and geometry. The rational analysis shows that the heat release rate for the Rotunda contents is greater than the Code-prescribed heat release rate. Hence, the Rotunda smoke exhaust system must have a capacity of 244,000 CFM as compared to 187,000 CFM under the Code-prescribed steady state fire.

1.0 INTRODUCTION

Nexus Technical Services Corporation (NTSC) was retained by Bennion Associates to perform a rational analysis of the Utah State Capitol Rotunda smoke evacuation system. NTSC reviewed the 1997 Uniform Building Code (UBC) to determine basic requirements for the Rotunda smoke evacuation system. NTSC then prepared heat release rates and smoke development calculations for two fire scenarios. Both scenarios are based on data obtained from reproductions of the original architectural drawings, dated September 27, 1912, and a letter from Neil Spencer to Wally Cooper dated April 14, 2000, detailing the normal and anticipated temporary interior furnishings. The rational analysis was performed to determine the approximate size of the rotunda exhaust fans required to maintain the ceiling smoke layer ten feet above the highest occupied floor level. Our rational analysis indicates that the heat release rate for the proposed rotunda contents would be greater than the code prescribed 5,000 Btu/sec. As a result, the minimum smoke exhaust fan size required to maintain the smoke layer at or above 10 feet above the highest occupied floor is approximately 243,596 cfm, as compared to 186,545 cfm, which would be required using the Code prescribed steady state fire.

2.0 BACKGROUND

The Capitol Building has three levels open to the rotunda. The first floor has large circulation spaces that are open to the rotunda. The second and third levels have balconies at the perimeter of the rotunda that are separated from the occupied floor spaces. The details for the project indicate that the permanent furniture and finishes include terrazzo and marble floors, metal doors, marble and plaster walls, canvas murals, wooden benches, a wooden information booth, metal stair rails, wood window frames in the upper rotunda and wood display cabinets.

The major concentration of temporary combustible materials will be on the first floor of the rotunda during the Christmas holidays and during the Governor's inauguration (see attached letter from Bennion Associates). The typical arrangement during the inauguration is to set up bleachers and a bandstand in the West wing of the first floor and up to six platforms, a piano and flags in the center rotunda. Additionally, in the east wing, approximately 350 chairs, coat racks, 20 6-foot tables and 16 8-foot tables will be set up.

3.0 PURPOSE

The purpose of this report is to determine the approximate sizing of smoke exhaust fans for the rotunda, based on expected fire scenarios.

4.0 METHODOLOGY

NTSC's rational analysis was based on criteria established by Section 905 of the UBC as well as formulas from NFPA 92B. The first step of the analysis of the two fire scenarios was to establish the building configuration and construction. The second step was to define the fuel load and resulting maximum heat release rate for each fire being modeled. Third, the formulas for the calculations were established. Formulas for smoke layer height and the smoke volumetric rate were determined.

The volumetric flow rate of smoke development was estimated using the equations from Section 3-7.1.2 of NFPA 92B (Section 905.5.2.2 of the UBC). In order to estimate the effect of smoke exhaust fans on the smoke plume, the smoke layer was held at 10 feet above the upper floor level (third floor) in accordance with the requirement of section 905.5.2.1 of the UBC.

4.1 Building Configuration

The first step of the analysis was to establish the building configuration and construction. Building information and details were taken from the Architect's drawings. Due to the configuration of the space, the configuration arrangement was simplified as allowed in NFPA 92B.

4.2 Fuel Load and Heat Release Rate

Our analysis modeled two scenarios, as well as a code mandated steady state fire, as follows:

1. The first scenario analyzed a fire that occurs in the center of the rotunda on the first floor and involves a Christmas tree (slightly dry), six (6) platforms, four (4) flags, one (1) podium and a piano. This scenario will produce an axisymmetric fire plume within the rotunda.

2. The second scenario analyzed a fire in the West wing of the rotunda and involves four (4) bandstand risers and bleachers that produce an axisymmetric fire plume within the West wing.

The third scenario is a steady state fire with a constant heat release rate of 5,000 BTU/sec.

4.2.1 Scenario 1

Fuel loads provided on the first floor consisted of the Christmas tree (slightly dry), platforms, flags, podium, and piano. Fuel load data for these combustible materials was derived from tabular information contained in the 2nd edition of the SFPE Handbook and the 1995 edition of NFPA 92B. From this information, the heat release rate was estimated using a peak heat release rate from data in the 1995 edition of NFPA 92B and a formula from the SFPE Handbook.

The first scenario assumes that the pine needles on the Christmas tree ignite first, resulting in a fast growth fire initially involving the tree only. The fire then spreads to other combustibles with a slow growth model as the larger tree branches and trunk continue to burn. After the needles and small branches of the Christmas tree are consumed, the fire decays until it meets the slow growth fire model. It is assumed that the peak heat release rate for the Christmas tree alone occurs during the fast fire growth period. An additional heat release rate contributed by the large branches and tree trunk is conservatively assumed in order to obtain the peak heat release rate during the slow fire growth period.

Once the heat release rate was determined, the equations in NFPA 92B were used to estimate the smoke layer height for an unsteady fire. The fire was assumed to start at each group of combustible materials simultaneously and grow in a t-squared fashion.

4.2.2 Scenario 2

The second scenario considered a fire on the first floor of the West wing in the bleachers and bandstand. The fire growth rate was considered slow.

4.2.3 Steady State Fire

The third scenario involves a code mandated steady state fire with a constant heat release rate of 5,000 BTU/sec.

4.3 Calculation Equations

The smoke layer height and the smoke volumetric rate were determined based on the following formulas:

4.3.1 Smoke Layer Height

4.3.1.1 Scenario 1

The position of the smoke layer below the ceiling is calculated by utilizing equation 10 in NFPA 92B, Section 3-6.2.2. This equation is as follows:

$$z/H = 0.23\ [t/(t_g^{2/5}\ H^{4/5}\ (A/H^2)^{3/5})]^{-1.45}$$

where, z = height of the first indications of smoke above the fire surface (ft)
H = ceiling height above the fire surface (ft)
t = time (sec)
t_g = growth rate (sec)
A = cross-sectional area of the space being filled with smoke (ft^2)

4.3.1.2 Scenario 2

The position of the smoke layer below the ceiling is calculated by utilizing the same methodology as Section 4.3.1.1.

4.3.1.3 Steady State Fire at 5000 Btu/s

The position of the smoke layer did not need to be calculated, since the heat release rate and the height of the smoke layer was held constant.

4.3.2 Smoke Volumetric Rate

4.3.2.1 Scenario 1

The smoke volumetric rate is estimated by the equation in the 1995 edition of NFPA 92B, equations 14 and 15. Since the type of plume is considered an axisymmetric plume for Scenario 1, the equation of mass flow rate for an axisymmetric plume is applied to this scenario. The equation is:

For $Z > Z_l$

$$m_p = 0.022Q_c^{1/3}Z^{5/3} + 0.0042\, Q_c$$

where, Q = heat release rate (Btu/s)
Q_c = convective heat release rate ($Q_c = 0.7Q$)
Z = height from top of fuel surface to bottom of smoke
Layer (ft)
Z_l = limiting flame height (ft) ($Z_l = 0.533\, Q_c^{2/5}$)
m_p = mass flow rate (lbs/s)

For Z £ Z_l

$$m_p = 0.0208Q_c^{3/5}\, Z$$

Since the smoke layer (Z) will be held at 40 feet, the equation for $Z > Z_l$ applies to this analysis.

To convert m_p from pounds per second of mass flow to a volumetric rate, the following formula is used. This formula is from NFPA 92B, equation 16.

$$V = 60m_p/r$$

where, V = volumetric rate (ft^3/min or cfm)
r = density of smoke layer (lb/ ft^3)

To determine the density of the smoke layer, the following formula is used. This formula is from NFPA 92B, Section A-3-7.1.5:

$$r/ro = 528/(460 + T)$$

where, r = density of smoke layer (lb/cuft)
ro = density of air = 0.065 (lb/cuft) @ 4500' above sea
level, 68°F
T = temperature of smoke (°F)

To determine the smoke layer temperature, the following formula is used. This formula is from

NFPA 92B, equation 4.

$$DT = 27,400 \, [\, t/(t_g^{\,2/5} H^{4/5}) - 0.22]^{4/3} \, / \, [t_g^{\,4/5} H^{3/5}]$$

where, DT = temperature rise within ceiling jet (°F)

t = time from ignition (sec)

t_g = growth rate (sec)

H = ceiling height (ft)

4.3.2.2 Scenario 2

The smoke volumetric rate for Scenario 2 is estimated by the same methodology as Section 4.3.2.1.

4.3.2.3 Steady State Fire

The smoke volumetric rate for the Steady State Fire is estimated by the same methodology as Section 4.3.2.1. However, the temperature rise of the smoke is predicted based on the following equation from NFPA 92B, equation 3:

$$X = 4.6 \times 10^{-4} \, Y^2 + 2.7 \times 10^{-15} \, Y^6$$

where, $X = t \, Q^{1/3} / H^{4/3}$

$Y = DT \, H^{5/3} / Q^{2/3}$

and where, t = time from ignition (sec)

Q = heat release rate (steady fire) (BTU/sec)

H = ceiling height above fire surface (ft)

ΔT = temperature rise within ceiling jet (°F)

5.0 ASSUMPTIONS

All assumptions are based on engineering approaches using available data and formulations. The two fires modeled are based on projected scenarios, but focus on real fires. Our analysis considers that unsteady fires are more closely related to real fire phenomenon. Therefore, the fire models performed are based on unsteady fires. In order to estimate accurate smoke production, it is assumed that the rotunda is not provided with vertical openings or exhaust fans. The smoke layer interface position addresses the hazard of people being immersed in a smoke layer on the third floor. In terms of the psychological effect, the smoke layer decreases the speed of evacuation in the case of a fire. By this aspect, the size of exhaust fan capacity may be designed to keep the position of the smoke layer at 10 ft above the upper floor level (third floor) based on the requirement of 1997 UBC, Section 905.5.2.1.

Additional assumptions are as follows:

- The smoke detection system design considers smoke stratification in the spacing and location of smoke detection devices.
- Smoke exhaust fans are activated automatically by the fire detection system.
- There is no sprinkler protection in the rotunda.
- The platforms have a metal frame with a wood top and are open on the sides.
- The bleachers have a metal frame with wood benches and are open on the sides and back. There are three separate 10 ft x 30 ft sections, spaced such that only one bleacher will be involved in Fire Scenario 2.
- The fire does not spread beyond the postulated scenarios due to spatial separation or substantial non-combustible construction.
- The wood platforms, bleachers and bandstand are made of Douglas Fir.
- The bandstand is made of four sections each 4 ft by 8 ft by 1 ft high.

5.1 Scenario 1

This scenario considered that the fire involved a slightly dry Christmas tree, six (6) platforms, four (4) flags, one (1) podium, and a piano. The fuel load was calculated based on the chemical property of the wood and test data from the 1995 edition of NFPA 92B using a formulation from the SFPE Handbook. The fire growth was considered as a fast fire initially, accounting for the rapid fire growth rate expected when the Christmas tree needles ignite, and eventually settling into a slow growth fire. The fire model was terminated when the peak heat release rate was reached.

5.2 Scenario 2

The second scenario analyzed a fire in the West wing of the rotunda and involves four (4) bandstand risers and bleachers. The fire growth rate was considered as a slow fire for the duration of the fire. The fuel load was estimated based on the chemical property of the wood and test data from the 1995 edition of NFPA 92B. The fire model was terminated when the peak heat release rate was reached.

6.0 CALCULATIONS

6.1 Building Configuration

The building configuration is based on the architect's drawings. The height of the rotunda from the first floor to the lowest point on the inside dome is 122 feet. The radius of the dome is 32 feet. The height of the East and West wings to the lowest point on the barrel vault ceiling is 34 feet. The radius of the barrel vault is 17'-6".

The fire model assumes that the ceiling in the rotunda and the West wing is flat and that the heights identified in the previous paragraph are 2/3 of the radius of the dome and barrel vault.

Based on the methodology in NFPA 92B, Section 3-6.2.4 (d), the space was evaluated based on an equivalent cross sectional area. Therefore, the rotunda was modeled based on one large compartment, rather than three smaller compartments.

The configuration is as follows:

Area	Ceiling Height (ft)	Depth (ft)	Length (ft)	Cross-Sectional Area (ft^2)	Floor Area (ft^2)
Center Rotunda	143	60	60	8,580	3,600
East & West Wings	45	60	60	2,700	3,600

The total cross-sectional area of the space is:

8,580 + (2) 2,700 = 13,980 square feet

Assuming that the equivalent compartment length is 180 feet, the equivalent height of the single compartment is:

13,980 / 180 = 77.67 feet (Use 78 feet)

Therefore, the equivalent single compartment has the following dimensions:

Area	Ceiling Height (ft)	Depth (ft)	Length (ft)	Cross-Sectional Area (ft^2)	Floor Area (ft^2)
Equivalent Compartment	78	60	180	13,980	10,800

6.2 Fuel Load and Heat Release Rates

The fuel configurations and loading are based on information provided by the facility. The calculation of the heat release rates are based on the data in the SFPE Handbook, 1995 Edition of NFPA 92B, and Fire Dynamics. The fire growth rate from incipient to the peak heat release rate is based on Appendix B of NFPA 72.

6.2.1 Scenario 1

The calculated heat release is based on a slightly dry Christmas tree, six (6) platforms, four (4) flags, one (1) podium, and a piano. The platforms are 4 ft long by 4 ft wide by 1 ft high and are made of wood. The fuel load of each wood platform is shown in the following table.

	SI Units	English Units
Mass Loss Rate per Unit Area (m”)	13 (g/m^2sec)	0.00257 (lb/ft^2sec)
Heat of Combustion (H_C)	21.0 (MJ/kg)	9,035 (Btu/lb)
Area of Fuel (Wood) (A)	1.4 (m^2)	16 (ft^2)
Heat Release Rate (Q)	382 (kW)	372 (Btu/sec)

Note:
1kg = 2.2 lb
1J = 9.5×10^{-4} Btu
1m = 3.33 ft
1.055 kW = 1 Btu/sec
Note: Heat Release Rate (Q) = A x m”x H_C (See Appendix B of NFPA 72)

Since there are six wood platforms, the fuel load for all six platforms is

372 BTU/sec x 6 = 2,232 BTU/sec

The following table provides Christmas tree burning rates based on testing:

Christmas Tree Burning Rates[1]

Test No.	Weight (lbs.)	Peak Heat Release Rate (kW)
1 (green tree)	14.3	69
2 (dry tree)	15.4	650
3 (dry tree)	16.3	500

It is assumed that the Christmas tree placed in the rotunda will be freshly cut and remain in the rotunda for approximately one month. During its time in the rotunda, it is expected that the tree will dry out slightly. Therefore, it is assumed that the burning characteristics of the tree will be similar to the characteristics that fall between the green tree and the dry trees that were tested.
The average peak heat release rate of the dry trees that were tested is:

(650 + 500) / 2 = 575 kW

The peak heat release rate at the midpoint of the rates for the green tree and the dry trees that were tested is:

(575 + 69) / 2 = 322 kW = 305 BTU/sec

Note: 1.055 kW = 1 BTU/sec

The peak heat release rate calculated above is for a tree that weighs approximately 15 pounds. The tree used in the rotunda is approximately 36 feet tall. To correlate the heat release rate above with the heat release rate of a burning 36-foot tree, the peak heat release rate is calculated below as a function of weight.

(305 BTU/sec) / 15 lbs = 20 BTU/sec per pound

According to the Virginia Polytechnic Institute and State University, Department of Wood Science & Forest Products, the weight of a 36-foot tree with an 18-inch diameter trunk is approximately 2,000 pounds. Approximately 25% of the weight is attributed to the needles and small branches, and up to 50% of the total weight is water.

The fire model of a burning 36-foot tree considers two phases of burning. The first phase involves a fast fire growth period in which all of the needles and small branches burn off at a fast rate, generating a large quantity of heat that results in the peak heat release rate for the Christmas tree alone. The second phase is a slow fire growth period where the trunk and larger branches burn at a much slower rate, and the remaining combustibles in the area are consumed. There is an additional peak heat release rate characterized by this slow fire growth period.
Given the size of the trunk (18-inch diameter), a fire is expected to penetrate only the outermost layers. In addition, 50% of the mass of the trunk is water. Therefore, it is assumed that the trunk, in

addition to the large branches, will not provide a significant source of combustion during the slow fire growth period.

The weight of the needles and small branches is:

0.25 x 2,000 lbs = 500 lbs

Therefore, the peak heat release rate is:

500 pounds x 20 BTU/sec per pound = 10,000 BTU/sec

For the flags, it is assumed that the material is cotton and the peak heat release rate is indicated in the 1995 edition of NFPA 92B, Table B-6. For the podium, the dimensions are assumed to be 2 ft by 2 ft by 3 ft. The surface area of the podium is 28 square feet. The heat release rate is based on the values in the referenced table. For the piano, the heat release rate is assumed to be similar to a 1/2" plywood wardrobe, per NFPA 72, Table B-2.2.2.3 (Approximately 3,000 BTU/sec).

The following table provides a summary of the peak heat release rates of the combustible materials involved in Scenario 1.

Combustible Materials	Heat Release Rate (kW)	Heat Release Rate (Btu/sec)
4 Flags	239	227
1 Wood Podium	686	650
6 Wood Platforms	2116	2,232
Christmas tree (slightly dry)	8,440	10,000
Piano	3,165	3,000

Since the peak heat release rate for only the Christmas tree occurs during the fast fire growth period, before the other materials reach their maximum rate of combustion, the combined peak heat release rate is not calculated by adding each of the values listed above. Rather, the total peak heat release rate for Scenario 1 is calculated as follows:

As explained above, the trunk and large braches are not expected to generate a large quantity of heat. It is conservatively assumed that at the time when all other materials reach their peak heat release rate, the maximum amount of heat that the Christmas tree will generate is 4,000 BTU/sec. Therefore, the total peak heat release rate for Scenario 1 is:

(227 + 650 + 2,232 + 4,000 + 3,000) BTU/sec = 10,109 BTU/sec

6.2.2 Scenario 2

The fuel load calculated is based on bleachers and a bandstand. The bleachers are 30 ft long by 30 ft wide by 4 ft 6 inches high and are made of wood. The sides and back are open, and the frame is made of metal. The bleachers are in three 10 ft by 30 ft sections, and only one section is involved in the fire. The fuel load of the bleachers is shown in the following table:

	SI Unit	English Unit
Mass Loss Rate per Unit Area (m”)	13 (g/m^2sec)	0.00257 (lb/ft^2sec)
Heat of Combustion (H_C)	21.0 (MJ/kg)	9,035 (Btu/lb)
Area of Fuel (Wood) (A)	27.1 (m^2)	300 (ft^2)
Heat Release Rate (Q)	7,349 (kW)	6,966 (Btu/sec)

Note:
1kg = 2.2 lb
1J = 9.5×10^{-4} Btu
1m = 3.33 ft
1.055 kW = 1 Btu/sec
Note: Heat Release Rate (Q) = A x m”x H_C

The bandstand is made of four sections each 4 ft by 8 ft by 1 ft high made of wood. The fuel load of each bandstand is shown in the following table:

	SI Unit	English Unit
Mass Loss Rate per Unit Area (m”)	13 (g/m^2sec)	0.00257 (lb/ft^2sec)
Heat of Combustion (H_C)	21.0 (MJ/kg)	9,035 (Btu/lb)
Area of Fuel (Wood) (A)	2.9 (m^2)	32 (ft^2)
Heat Release Rate (Q)	784 (kW)	743 (Btu/sec)

Note:
1kg = 2.2 lb
1J = 9.5×10^{-4} Btu
1m = 3.33 ft
1.055 kW = 1 Btu/sec
Note: Heat Release Rate (Q) = A x m”x H_C (See Appendix B of NFPA 72)

Since there are four sections of bandstand risers, the heat release rate is:

743 BTU/sec x 4 = 2,972 Btu/sec (3,135 kW)

Total peak heat release rate for scenario 2 is calculated as 9,938 Btu/s.

6.2.3 Steady State Fire

The heat release rate of 5000 Btu/s is prescribed by 1997 UBC, Sect. 905.6.1. The formulation is based on the 1997 UBC and 1995 NFPA 92B. This fire scenario is based on a fire occurring on the first floor of the rotunda with a constant heat release rate of 5000 Btu/sec during 30 minutes. There are no openings or exhaust fans in the rotunda. The type of smoke plume is an axisymmetric plume.

6.3 Volumetric Rate Calculation

6.3.1 Scenario 1

The calculations showing the Heat Release Rate and the Volumetric Rate of Smoke Production, as well as calculated intermediate values such as convective heat release rate, mass flow rate, temperature rise and smoke layer height, are included in Attachment A.

6.3.2 Scenario 2

The calculations showing the Heat Release Rate and the Volumetric Rate of Smoke Production, as well as calculated intermediate values such as convective heat release rate, mass flow rate, temperature rise and smoke layer height, are included in Attachment B.

6.3.3 Steady State Fire

The constant heat release rate is 5000 Btu/s.

For the steady state fire, the volumetric rate is calculated below:

$m_p = 0.022Q_c^{1/3}Z^{5/3} + 0.0042\ Q_c$

where, Q = heat release rate, 5000 Btu/sec

Q_c = convective heat release rate ($Q_c = 0.7Q = 3{,}500$ Btu/sec)

Z = height from top of fuel surface to bottom of smoke Layer (78 ft maximum)

m_p = mass flow rate (lbs/s)

$$m_p = (0.022(3{,}500)^{1/3}(40)^{5/3})+0.0042(3{,}500)$$

$$m_p = 171 \text{ lb/sec}$$

The maximum temperature rise during the steady state fire is calculated as follows:

$$X = 4.6 \times 10^{-4}\ Y^2 + 2.7 \times 10^{-15}\ Y^6$$

$$X = t\ Q^{1/3} / H^{4/3}$$

$$Y = DT\ H^{5/3} / Q^{2/3}$$

t = time from ignition (1,900 sec)

Q = heat release rate (steady fire) (5,000 BTU/sec)
H = ceiling height above fire surface (78 ft)
DT = temperature rise within ceiling jet (°F)

Solving the above equation for DT at 1900 seconds (based on the duration of scenarios 1 and 2), the temperature rise is approximately 87 °F. Based on an ambient temperature of 68 °F, the smoke temperature is 155 °F.

The smoke density is, therefore:

$$r = ro \times (528/(460 + T)) = 0.065 \times (528/(460 + 162)) = 0.055 \text{ lb/ft}^3$$

Therefore, the volumetric rate is calculated as follows:

$$V = 60m_p/r = 60(171)/0.055 = \underline{186{,}545 \text{ cfm}}$$

7.0 SUMMARY OF RESULTS AND CONCLUSIONS

Scenario	Scenario 1	Scenario 2	Steady State Fire
Location	First Floor	First Floor	First Floor
Fire Origin	Center	Center	Center
Peak Heat Release Rate (Btu/s)	10,109	9,938	5,000
Time [1] (sec)	200	350	N/A
Volumetric Rate [2] (ft^3/min, cfm)	243,596	242,279	186,545

The result of fuel load (heat release rate) and volumetric rates for scenarios 1, 2 and the steady state fire, is summarized in the following table.

Notes:
1. Estimated time when smoke layer reaches a level 10 ft above the third floor.
2. The calculated volumetric rate for the smoke exhaust system necessary to keep the position of the smoke layer at 10 ft above the third floor.

In Scenario 1 the smoke layer reaches 10 ft above the third floor at 3 minutes, 20 seconds (200 sec), and the maximum smoke volumetric rate (243,596 cfm) was calculated at 1910 seconds, when the heat release rate reaches the maximum value.

In the case of Scenario 2, the smoke layer reaches 10 ft above the third floor at 5 minutes, 50 seconds (350 sec), and the maximum smoke volumetric rate (242,279 cfm) was calculated at 1900 seconds, when the heat release rate reaches the maximum value.

As a result, the calculated volumetric flow rate of the exhaust fans required to maintain the smoke level at or above 10 ft above the third floor is 243,596 cfm.

For a steady state fire of 5,000 Btu/s, the volumetric rate is determined as 186,545 cfm. In a real fire scenario, it is not likely that a fire will start at 5,000 Btu/s and burn constantly during the fire incident. Therefore, the unsteady fire modeled in the rational analysis is more realistic for sizing the smoke exhaust fans.

8.0 REFERENCES

1. Uniform Building Code (UBC), Volume 1, 1997 edition

2. National Fire Protection Association, NFPA 72, National Fire Alarm Code", 1995 edition

3. National Fire Protection Association, NFPA 92B, " Smoke Management in Malls, Atria and Large Areas", 1995 edition

4. SFPE Handbook of Fire Protection Engineering, 2nd Edition

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke layer delta T (oF)
0	150	0	0	0	0	78	0
10	150	4.4	3.1	45.7	42,226	78	0
20	150	17.8	12.4	72.6	67,059	78	0
30	150	40	28	95.2	87,917	78	0
40	150	71.1	49.8	115.4	106,566	78	0
50	150	111.1	77.8	134	123,736	78	0
60	150	160	112	151.5	139,903	78	0.3
70	150	217.8	152.4	168	155,368	78	1
80	150	284.4	199.1	183.8	170,248	78	1.9
90	150	360	252	198.9	184,651	78	2.9
100	150	444.4	311.1	213.6	198,663	78	4.1
110	150	537.8	376.4	227.8	212,349	78	5.3
120	150	640	448	241.6	225,761	78	6.5
130	150	751.1	525.8	227.8	213,429	72.8	7.9
140	150	871.1	609.8	200.7	188,542	65.4	9.3
150	150	1000	700	178.6	168,181	59.2	10.7
160	150	1137.8	796.4	160.2	151,318	53.9	12.2
170	150	1284.4	899.1	144.9	137,204	49.4	13.8
180	150	1440	1008	131.9	125,285	45.4	15.4
190	150	1604.4	1123.1	120.8	115,143	42	17
200	150	1777.8	1244.4	115.9	110,804	40	18.7
210	150	1960	1372	120.1	115,175	40	20.4
220	150	2151.1	1505.8	124.3	119,549	40	22.2
230	150	2351.1	1645.8	128.4	123,929	40	23.9
240	150	2560	1792	132.5	128,318	40	25.8
250	150	2777.8	1944.4	136.6	132,721	40	27.6
260	150	3004.4	2103.1	140.7	137,138	40	29.5
270	150	3240	2268	144.8	141,574	40	31.4
280	150	3484.4	2439.1	148.8	146,029	40	33.4
290	150	3737.8	2616.4	152.8	150,507	40	35.4
300	150	4000	2800	156.8	155,009	40	37.4
310	150	4271.1	2989.8	160.8	159,537	40	39.4
320	150	4551.1	3185.8	164.8	164,093	40	41.5
330	150	4840	3388	168.8	168,679	40	43.5
340	150	5137.8	3596.4	172.8	173,296	40	45.6
350	150	5444.4	3811.1	176.8	177,946	40	47.8
360	150	5760	4032	180.8	182,631	40	49.9
370	150	6084.4	4259.1	184.7	187,350	40	52.1
380	150	6417.8	4492.4	188.7	192,107	40	54.3
390	150	6760	4732	192.7	196,902	40	56.6
400	150	7111.1	4977.8	196.6	201,737	40	58.8
410	150	7471.1	5229.8	200.6	206,612	40	61.1
420	150	7840	5488	204.6	211,529	40	63.4

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke layer delta T (oF)
430	150	8217.8	5752.4	208.6	216,489	40	65.7
440	150	8604.4	6023.1	212.6	221,493	40	68
450	150	9000	6300	216.6	226,542	40	70.4
460	150	9404.4	6583.1	220.5	231,637	40	72.8
470	150	9817.8	6872.4	224.6	236,779	40	75.2
475	150	10027.8	7019.4	226.6	239,368	40	76.4
480	-150	9817.8	6872.4	224.6	236,779	40	75.2
490	-150	9404.4	6583.1	220.5	231,637	40	72.8
500	-150	9000	6300	216.6	231,637	40	70.4
510	-150	8604.4	6023.1	212.6	221,493	40	68
520	-150	8217.8	5752.4	208.6	216,489	40	65.7
530	-150	7840	5488	204.6	211,529	40	63.4
540	-150	7471.1	5229.8	200.6	206,612	40	61.1
550	-150	7111.1	4977.8	196.6	201,737	40	58.8
560	-150	6760	4732	192.7	196,902	40	56.6
570	-150	6417.8	4492.4	188.7	192,107	40	54.3
580	-150	6084.4	4259.1	184.7	187,350	40	52.1
590	-150	5760	4032	180.8	182,631	40	49.9
600	-150	5444.4	3811.1	176.8	177,946	40	47.8
610	-150	5137.8	3596.4	172.8	173,296	40	45.6
620	-150	4840	3388	168.8	168,679	40	43.5
630	-150	4551.1	3185.8	164.8	164,093	40	41.5
640	-150	4271.1	2989.8	160.8	159,537	40	39.4
650	-150	4000	2800	156.8	155,009	40	37.4
660	-150	3737.8	2616.4	152.8	150,507	40	35.4
670	-150	3484.4	2439.1	148.8	146,029	40	33.4
680	-150	3240	2268	144.8	141,574	40	31.4
690	-150	3004.4	2103.1	140.7	137,610	40	31.4
700	-150	2777.8	1944.4	136.6	133,172	40	29.5
710	-150	2560	1792	132.5	128,749	40	27.6
720	-150	2351.1	1645.8	128.4	125,610	40	31.4
730	-150	2151.1	1505.8	124.3	120,737	40	27.6
740	-150	1960	1372	120.1	116,302	40	25.8
750	-150	1777.8	1244.4	115.9	111,870	40	23.9
760	600	1604.4	1123.1	111.7	107,441	40	22.2
770	600	1646.9	1152.9	112.8	108,549	40	22.6
780	600	1690	1183	113.8	109,657	40	23.1
790	600	1733.6	1213.5	114.9	110,765	40	23.5
800	600	1777.8	1244.4	115.9	111,873	40	24
810	600	1822.5	1275.8	117	112,981	40	24.4
820	600	1867.8	1307.4	118	114,089	40	24.9
830	600	1913.6	1339.5	119.1	115,197	40	25.3
840	600	1960	1372	120.1	116,305	40	25.8

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke layer delta T (oF)
850	600	2006.9	1404.9	121.2	117,414	40	26.2
860	600	2054.4	1438.1	122.2	118,522	40	26.7
870	600	2102.5	1471.8	123.3	119,631	40	27.2
880	600	2151.1	1505.8	124.3	120,740	40	27.6
890	600	2200.3	1540.2	125.3	121,850	40	28.1
900	600	2250	1575	126.4	122,960	40	28.6
910	600	2300.3	1610.2	127.4	124,071	40	29.1
920	600	2351.1	1645.8	128.4	125,182	40	29.5
930	600	2402.5	1681.8	129.5	126,294	40	30
940	600	2454.4	1718.1	130.5	127,407	40	30.5
950	600	2506.9	1754.9	131.5	128,520	40	31
960	600	2560	1792	132.5	129,634	40	31.4
970	600	2613.6	1829.5	133.6	130,749	40	31.9
980	600	2667.8	1867.4	134.6	131,865	40	32.4
990	600	2722.5	1905.8	135.6	132,982	40	32.9
1000	600	2777.8	1944.4	136.6	134,099	40	33.4
1010	600	2833.6	1983.5	137.7	135,218	40	33.9
1020	600	2890	2023	138.7	136,338	40	34.4
1030	600	2946.9	2062.9	139.7	137,458	40	34.9
1040	600	3004.4	2103.1	140.7	138,580	40	35.4
1050	600	3062.5	2143.8	141.7	139,703	40	35.9
1060	600	3121.1	2184.8	142.7	140,827	40	36.4
1070	600	3180.3	2226.2	143.7	141,953	40	36.9
1080	600	3240	2268	144.8	143,079	40	37.4
1090	600	3300.3	2310.2	145.8	144,207	40	37.9
1100	600	3361.1	2352.8	146.8	145,336	40	38.4
1110	600	3422.5	2395.8	147.8	146,467	40	38.9
1120	600	3484.4	2439.1	148.8	147,598	40	39.4
1130	600	3546.9	2482.9	149.8	148,732	40	39.9
1140	600	3610	2527	150.8	149,867	40	40.4
1150	600	3673.6	2571.5	151.8	151,003	40	41
1160	600	3737.8	2616.4	152.8	152,141	40	41.5
1170	600	3802.5	2661.8	153.8	153,280	40	42
1180	600	3867.8	2707.4	154.8	154,421	40	42.5
1190	600	3933.6	2753.5	155.8	155,563	40	43
1200	600	4000	2800	156.8	156,707	40	43.6
1210	600	4066.9	2846.9	157.8	157,853	40	44.1
1220	600	4134.4	2894.1	158.8	159,001	40	44.6
1230	600	4202.5	2941.8	159.8	160,150	40	45.1
1240	600	4271.1	2989.8	160.8	161,301	40	45.7
1250	600	4340.3	3038.2	161.8	162,454	40	46.2
1260	600	4410	3087	162.8	163,608	40	46.7
1270	600	4480.3	3136.2	163.8	164,765	40	47.3

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke layer delta T (oF)
1280	600	4551.1	3185.8	164.8	165,923	40	47.8
1290	600	4622.5	3235.8	165.8	167,083	40	48.3
1300	600	4694.4	3286.1	166.8	168,245	40	48.9
1310	600	4766.9	3336.9	167.8	169,409	40	49.4
1320	600	4840	3388	168.8	170,575	40	50
1330	600	4913.6	3439.5	169.8	171,743	40	50.5
1340	600	4987.8	3491.4	170.8	172,913	40	51
1350	600	5062.5	3543.8	171.8	174,085	40	51.6
1360	600	5137.8	3596.4	172.8	175,259	40	52.1
1370	600	5213.6	3649.5	173.8	176,435	40	52.7
1380	600	5290	3703	174.8	177,613	40	53.2
1390	600	5366.9	3756.9	175.8	178,793	40	53.8
1400	600	5444.4	3811.1	176.8	179,976	40	54.3
1410	600	5522.5	3865.8	177.8	181,161	40	54.9
1420	600	5601.1	3920.8	178.8	182,347	40	55.5
1430	600	5680.3	3976.2	179.8	183,536	40	56
1440	600	5760	4032	180.8	184,728	40	56.6
1450	600	5840.3	4088.2	181.7	185,921	40	57.1
1460	600	5921.1	4144.8	182.7	187,117	40	57.7
1470	600	6002.5	4201.8	183.7	188,315	40	58.3
1480	600	6084.4	4259.1	184.7	189,516	40	58.8
1490	600	6166.9	4316.9	185.7	190,718	40	59.4
1500	600	6250	4375	186.7	191,924	40	60
1510	600	6333.6	4433.5	187.7	193,131	40	60.5
1520	600	6417.8	4492.4	188.7	194,341	40	61.1
1530	600	6502.5	4551.8	189.7	195,553	40	61.7
1540	600	6587.8	4611.4	190.7	196,768	40	62.2
1550	600	6673.6	4671.5	191.7	197,985	40	62.8
1560	600	6760	4732	192.7	199,205	40	63.4
1570	600	6846.9	4792.9	193.7	200,427	40	64
1580	600	6934.4	4854.1	194.7	201,652	40	64.6
1590	600	7022.5	4915.8	195.7	202,879	40	65.1
1600	600	7111.1	4977.8	196.6	204,109	40	65.7
1610	600	7200.3	5040.2	197.6	205,342	40	66.3
1620	600	7290	5103	198.6	206,577	40	66.9
1630	600	7380.3	5166.2	199.6	207,814	40	67.5
1640	600	7471.1	5229.8	200.6	209,055	40	68
1650	600	7562.5	5293.8	201.6	210,297	40	68.6
1660	600	7654.4	5358.1	202.6	211,543	40	69.2
1670	600	7746.9	5422.9	203.6	212,791	40	69.8
1680	600	7840	5488	204.6	214,042	40	70.4
1690	600	7933.6	5553.5	205.6	215,296	40	71
1700	600	8027.8	5619.4	206.6	216,552	40	71.6

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke layer delta T (oF)
1710	600	8122.5	5685.8	207.6	217,811	40	72.2
1720	600	8217.8	5752.4	208.6	219,073	40	72.8
1730	600	8313.6	5819.5	209.6	220,338	40	73.4
1740	600	8410	5887	210.6	221,605	40	74
1750	600	8506.9	5954.9	211.6	222,876	40	74.6
1760	600	8604.4	6023.1	212.6	224,149	40	75.2
1770	600	8702.5	6091.8	213.6	225,425	40	75.8
1780	600	8801.1	6160.8	214.6	226,704	40	76.4
1790	600	8900.3	6230.2	215.6	227,985	40	77
1800	600	9000	6300	216.6	229,270	40	77.6
1810	600	9100.3	6370.2	217.6	230,557	40	78.2
1820	600	9201.1	6440.8	218.6	231,848	40	78.8
1830	600	9302.5	6511.8	219.6	233,141	40	79.4
1840	600	9404.4	6583.1	220.5	234,438	40	80
1850	600	9506.9	6654.9	221.5	235,737	40	80.6
1860	600	9610	6727	222.5	237,039	40	81.2
1870	600	9713.6	6799.5	223.5	238,345	40	81.9
1880	600	9817.8	6872.4	224.6	239,653	40	82.5
1890	600	9922.5	6945.8	225.6	240,964	40	83.1
1900	600	10027.8	7019.4	226.6	242,279	40	83.7
1910	600	10133.6	7093.5	227.6	243,596	40	84.3

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke Layer delta T (oF)
0	600	0	0	0	0	78	0
10	600	0.3	0.2	18.1	16,753	78	0
20	600	1.1	0.8	28.8	26,596	78	0
30	600	2.5	1.8	37.8	34,854	78	0
40	600	4.4	3.1	45.7	42,226	78	0
50	600	6.9	4.9	53.1	49,004	78	0
60	600	10	7	60	55,343	78	0
70	600	13.6	9.5	66.5	61,340	78	0
80	600	17.8	12.4	72.6	67,059	78	0
90	600	22.5	15.8	78.6	72,546	78	0
100	600	27.8	19.4	84.3	77,842	78	0.1
110	600	33.6	23.5	89.9	82,978	78	0.2
120	600	40	28	95.2	87,969	78	0.3
130	600	46.9	32.9	100.5	92,832	78	0.5
140	600	54.4	38.1	105.6	97,580	78	0.6
150	600	62.5	43.8	110.6	102,225	78	0.8
160	600	71.1	49.8	115.4	106,775	78	1
170	600	80.3	56.2	120.2	111,241	78	1.3
180	600	90	63	124.9	115,627	78	1.5
190	600	100.3	70.2	129.5	119,942	78	1.7
200	600	111.1	77.8	134	124,190	78	1.9
210	600	122.5	85.8	138.5	128,376	78	2.2
220	600	134.4	94.1	136.6	126,658	75.9	2.4
230	600	146.9	102.9	126.4	117,297	71.2	2.7
240	600	160	112	117.4	108,997	66.9	3
250	600	173.6	121.5	109.4	101,601	63.1	3.2
260	600	187.8	131.4	102.2	94,981	59.6	3.5
270	600	202.5	141.8	95.8	89,031	56.4	3.8
280	600	217.8	152.4	89.9	83,662	53.5	4.1
290	600	233.6	163.5	84.7	78,801	50.9	4.4
300	600	250	175	79.9	74,385	48.4	4.7
310	600	266.9	186.9	75.5	70,362	46.2	5
320	600	284.4	199.1	71.5	66,685	44.1	5.3
330	600	302.5	211.8	67.9	63,316	42.2	5.6
340	600	321.1	224.8	64.5	60,222	40.4	5.9
350	600	340.3	238.2	64.8	60,522	40	6.2
360	600	360	252	66.1	61,744	40	6.5
370	600	380.3	266.2	67.3	62,958	40	6.9
380	600	401.1	280.8	68.6	64,166	40	7.2
390	600	422.5	295.8	69.8	65,367	40	7.5
400	600	444.4	311.1	71	66,563	40	7.9
410	600	466.9	326.9	72.3	67,752	40	8.2
420	600	490	343	73.5	68,937	40	8.6
430	600	513.6	359.5	74.7	70,117	40	8.9

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke Layer delta T (oF)
440	600	537.8	376.4	75.9	71,291	40	9.3
450	600	562.5	393.8	77.1	72,462	40	9.6
460	600	587.8	411.4	78.3	73,628	40	10
470	600	613.6	429.5	79.5	74,789	40	10.4
480	600	640	448	80.6	75,947	40	10.7
490	600	666.9	466.9	81.8	77,102	40	11.1
500	600	694.4	486.1	83	78,253	40	11.5
510	600	722.5	505.8	84.1	79,400	40	11.9
520	600	751.1	525.8	85.3	80,545	40	12.2
530	600	780.3	546.2	86.4	81,686	40	12.6
540	600	810	567	87.6	82,825	40	13
550	600	840.3	588.2	88.7	83,961	40	13.4
560	600	871.1	609.8	89.8	85,095	40	13.8
570	600	902.5	631.8	91	86,227	40	14.2
580	600	934.4	654.1	92.1	87,356	40	14.6
590	600	966.9	676.9	93.2	88,483	40	15
600	600	1000	700	94.3	89,609	40	15.4
610	600	1033.6	723.5	95.4	90,732	40	15.8
620	600	1067.8	747.4	96.5	91,854	40	16.2
630	600	1102.5	771.8	97.7	92,974	40	16.6
640	600	1137.8	796.4	98.8	94,093	40	17
650	600	1173.6	821.5	99.8	95,210	40	17.4
660	600	1210	847	100.9	96,327	40	17.9
670	600	1246.9	872.9	102	97,442	40	18.3
680	600	1284.4	899.1	103.1	98,556	40	18.7
690	600	1322.5	925.8	104.2	99,669	40	19.1
700	600	1361.1	952.8	105.3	100,781	40	19.6
710	600	1400.3	980.2	106.4	101,892	40	20
720	600	1440	1008	107.4	103,003	40	20.4
730	600	1480.3	1036.2	108.5	104,113	40	20.9
740	600	1521.1	1064.8	109.6	105,223	40	21.3
750	600	1562.5	1093.8	110.6	106,332	40	21.7
760	600	1604.4	1123.1	111.7	107,441	40	22.2
770	600	1646.9	1152.9	112.8	108,549	40	22.6
780	600	1690	1183	113.8	109,657	40	23.1
790	600	1733.6	1213.5	114.9	110,765	40	23.5
800	600	1777.8	1244.4	115.9	111,873	40	24
810	600	1822.5	1275.8	117	112,981	40	24.4
820	600	1867.8	1307.4	118	114,089	40	24.9
830	600	1913.6	1339.5	119.1	115,197	40	25.3
840	600	1960	1372	120.1	116,305	40	25.8
850	600	2006.9	1404.9	121.2	117,414	40	26.2
860	600	2054.4	1438.1	122.2	118,522	40	26.7
870	600	2102.5	1471.8	123.3	119,631	40	27.2

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke Layer delta T (oF)
880	600	2151.1	1505.8	124.3	120,740	40	27.6
890	600	2200.3	1540.2	125.3	121,850	40	28.1
900	600	2250	1575	126.4	122,960	40	28.6
910	600	2300.3	1610.2	127.4	124,071	40	29.1
920	600	2351.1	1645.8	128.4	125,182	40	29.5
930	600	2402.5	1681.8	129.5	126,294	40	30
940	600	2454.4	1718.1	130.5	127,407	40	30.5
950	600	2506.9	1754.9	131.5	128,520	40	31
960	600	2560	1792	132.5	129,634	40	31.4
970	600	2613.6	1829.5	133.6	130,749	40	31.9
980	600	2667.8	1867.4	134.6	131,865	40	32.4
990	600	2722.5	1905.8	135.6	132,982	40	32.9
1000	600	2777.8	1944.4	136.6	134,099	40	33.4
1010	600	2833.6	1983.5	137.7	135,218	40	33.9
1020	600	2890	2023	138.7	136,338	40	34.4
1030	600	2946.9	2062.9	139.7	137,458	40	34.9
1040	600	3004.4	2103.1	140.7	138,580	40	35.4
1050	600	3062.5	2143.8	141.7	139,703	40	35.9
1060	600	3121.1	2184.8	142.7	140,827	40	36.4
1070	600	3180.3	2226.2	143.7	141,953	40	36.9
1080	600	3240	2268	144.8	143,079	40	37.4
1090	600	3300.3	2310.2	145.8	144,207	40	37.9
1100	600	3361.1	2352.8	146.8	145,336	40	38.4
1110	600	3422.5	2395.8	147.8	146,467	40	38.9
1120	600	3484.4	2439.1	148.8	147,598	40	39.4
1130	600	3546.9	2482.9	149.8	148,732	40	39.9
1140	600	3610	2527	150.8	149,867	40	40.4
1150	600	3673.6	2571.5	151.8	151,003	40	41
1160	600	3737.8	2616.4	152.8	152,141	40	41.5
1170	600	3802.5	2661.8	153.8	153,280	40	42
1180	600	3867.8	2707.4	154.8	154,421	40	42.5
1190	600	3933.6	2753.5	155.8	155,563	40	43
1200	600	4000	2800	156.8	156,707	40	43.6
1210	600	4066.9	2846.9	157.8	157,853	40	44.1
1220	600	4134.4	2894.1	158.8	159,001	40	44.6
1230	600	4202.5	2941.8	159.8	160,150	40	45.1
1240	600	4271.1	2989.8	160.8	161,301	40	45.7
1250	600	4340.3	3038.2	161.8	162,454	40	46.2
1260	600	4410	3087	162.8	163,608	40	46.7
1270	600	4480.3	3136.2	163.8	164,765	40	47.3
1280	600	4551.1	3185.8	164.8	165,923	40	47.8
1290	600	4622.5	3235.8	165.8	167,083	40	48.3
1300	600	4694.4	3286.1	166.8	168,245	40	48.9
1310	600	4766.9	3336.9	167.8	169,409	40	49.4

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke Layer delta T (oF)
1320	600	4840	3388	168.8	170,575	40	50
1330	600	4913.6	3439.5	169.8	171,743	40	50.5
1340	600	4987.8	3491.4	170.8	172,913	40	51
1350	600	5062.5	3543.8	171.8	174,085	40	51.6
1360	600	5137.8	3596.4	172.8	175,259	40	52.1
1370	600	5213.6	3649.5	173.8	176,435	40	52.7
1380	600	5290	3703	174.8	177,613	40	53.2
1390	600	5366.9	3756.9	175.8	178,793	40	53.8
1400	600	5444.4	3811.1	176.8	179,976	40	54.3
1410	600	5522.5	3865.8	177.8	181,161	40	54.9
1420	600	5601.1	3920.8	178.8	182,347	40	55.5
1430	600	5680.3	3976.2	179.8	183,536	40	56
1440	600	5760	4032	180.8	184,728	40	56.6
1450	600	5840.3	4088.2	181.7	185,921	40	57.1
1460	600	5921.1	4144.8	182.7	187,117	40	57.7
1470	600	6002.5	4201.8	183.7	188,315	40	58.3
1480	600	6084.4	4259.1	184.7	189,516	40	58.8
1490	600	6166.9	4316.9	185.7	190,718	40	59.4
1500	600	6250	4375	186.7	191,924	40	60
1510	600	6333.6	4433.5	187.7	193,131	40	60.5
1520	600	6417.8	4492.4	188.7	194,341	40	61.1
1530	600	6502.5	4551.8	189.7	195,553	40	61.7
1540	600	6587.8	4611.4	190.7	196,768	40	62.2
1550	600	6673.6	4671.5	191.7	197,985	40	62.8
1560	600	6760	4732	192.7	199,205	40	63.4
1570	600	6846.9	4792.9	193.7	200,427	40	64
1580	600	6934.4	4854.1	194.7	201,652	40	64.6
1590	600	7022.5	4915.8	195.7	202,879	40	65.1
1600	600	7111.1	4977.8	196.6	204,109	40	65.7
1610	600	7200.3	5040.2	197.6	205,342	40	66.3
1620	600	7290	5103	198.6	206,577	40	66.9
1630	600	7380.3	5166.2	199.6	207,814	40	67.5
1640	600	7471.1	5229.8	200.6	209,055	40	68
1650	600	7562.5	5293.8	201.6	210,297	40	68.6
1660	600	7654.4	5358.1	202.6	211,543	40	69.2
1670	600	7746.9	5422.9	203.6	212,791	40	69.8
1680	600	7840	5488	204.6	214,042	40	70.4
1690	600	7933.6	5553.5	205.6	215,296	40	71
1700	600	8027.8	5619.4	206.6	216,552	40	71.6
1710	600	8122.5	5685.8	207.6	217,811	40	72.2
1720	600	8217.8	5752.4	208.6	219,073	40	72.8
1730	600	8313.6	5819.5	209.6	220,338	40	73.4
1740	600	8410	5887	210.6	221,605	40	74
1750	600	8506.9	5954.9	211.6	222,876	40	74.6

Time (sec)	Growth Rate (sec)	Heat Release Rate (Q) (BTU/sec)	Convective Heat Release Rate (Qc) (BTU/sec)	Mass Flow Rate (lb/sec)	Volumetric Rate (cfm)	Height of Smoke Layer (z) (ft)	Smoke Layer delta T (oF)
1760	600	8604.4	6023.1	212.6	224,149	40	75.2
1770	600	8702.5	6091.8	213.6	225,425	40	75.8
1780	600	8801.1	6160.8	214.6	226,704	40	76.4
1790	600	8900.3	6230.2	215.6	227,985	40	77
1800	600	9000	6300	216.6	229,270	40	77.6
1810	600	9100.3	6370.2	217.6	230,557	40	78.2
1820	600	9201.1	6440.8	218.6	231,848	40	78.8
1830	600	9302.5	6511.8	219.6	233,141	40	79.4
1840	600	9404.4	6583.1	220.5	234,438	40	80
1850	600	9506.9	6654.9	221.5	235,737	40	80.6
1860	600	9610	6727	222.5	237,039	40	81.2
1870	600	9713.6	6799.5	223.5	238,345	40	81.9
1880	600	9817.8	6872.4	224.6	239,653	40	82.5
1890	600	9922.5	6945.8	225.6	240,964	40	83.1
1900	600	10027.8	7019.4	226.6	242,279	40	83.7